

## LOGIC LEVEL VOLTAGE TRANSLATOR

### BACKGROUND OF INVENTION

#### 1. Field of Invention

5 The invention relates to operating voltage levels of integrated circuits. In particular, the invention relates to apparatus and methods for translating voltage levels of signals traveling between integrated circuits that operate at different voltage levels.

#### 2. Discussion of Related Art

Electronic systems often include circuits that operate at relatively low voltages, at  
10 times including core logic circuits and memory circuits, and other circuits that operate at higher voltages. Such mixed-mode voltage systems typically require voltage translation and voltage clamping capabilities. Voltage translation components allow proper communication of the I/O signals traveling between circuits operating at different voltage levels.

15 Circuits that employ transistors having smaller gate dimensions typically require an associated decrease in supply voltage level. Microprocessors and memory circuits, for example, often are fabricated with transistors having the smallest possible gate sizes. Thus, electronic systems, such as a cellular telephones and personal computers, will typically have components, such as processors, that operate at a low internal voltage, and  
20 additional components that operate at a relatively high external voltage. While an internal voltage supply may provide, for example, 2.5V, 1.5V or 0.9V, external voltage supplies may provide, for example, 5V, 3.3V or 2.5V.

Voltage translation circuits can provide uni- or bidirectional conversion of the low- and high-voltage signals produced by the circuits using the different supply voltage  
25 levels. Often, for example, a level-shifting circuit is used to increase the upper voltage-level swing of the low-voltage signals produced by high-performance complimentary metal-oxide-semiconductor (CMOS) logic devices. Unfortunately, a level-shifting circuit may fail to function properly when an internal voltage supply is producing less than its full operating voltage. Moreover, level-shifting circuits can introduce distortions  
30 and/or delays in the low-voltage signals that they convert to high-voltage signals.

## SUMMARY OF INVENTION

The invention arises, in part, from the realization that a voltage level shifting circuit can include an enabling circuit to prevent incorrect operation and unnecessary power use when an internal voltage supply is not ready for normal operation. The invention also arises, in part, from the realization that a voltage level shifting circuit can include a signal stabilizing circuit to improve, for example, the shape and delay characteristics of a shifted signal.

Accordingly, in a first aspect, the invention features a voltage level translator that provides an output signal having an external voltage in response to an input signal having an internal voltage. The voltage level translator includes first and second input signal transistors, first and second output signal transistors, and includes a signal stabilization circuit and/or an enable circuit.

The gate of the first input signal transistor receives the input signal, and the gate of the second input signal transistor receives an input complementary signal. The drain of the first output signal transistor is connected to the gate of the second output signal transistor, to the drain of the first input signal transistor, and to an output complementary signal node. The drain of the second output signal transistor is connected to the gate of the first output signal transistor, to the drain of the second input signal transistor, and to an output signal node. The signal stabilization circuit is connected to the drains of the first and second input signal transistors to modify a pulse parameter of the output signal at the output signal node.

The first and second output signal transistors can be high voltage transistors. The external voltage can have a value in a range of, for example, about 2.0 volts to about 10.0 volts, and the internal voltage can have a value in a range of, for example, about 0.5 volt to about 2.0 volts. The first and second input signal transistors can be n-channel MOS (NMOS) transistors. The first and second input signal transistors can be low voltage transistors.

The translator can further include first and second high voltage transistors that each have essentially zero threshold voltage and mediate the connection between the first and second input signal transistors and the first and second output signal transistors. The translator can further include a cascode circuit. The zero-threshold transistors and the

cascode circuit can protect the drains of the first and second input signal transistors from the external voltage.

The signal-stabilization circuit can include first and second signal stabilization transistors. The drain of the first signal-stabilization transistor can be connected to the drain of the first input signal transistor, and the drain of the second signal-stabilization transistor can be connected to the drain of the second input signal transistor. The sources of the first and second signal-stabilization transistors can be connected to an internal voltage supply. The gate of the first signal-stabilization transistor can receive the input signal, and the gate of the second signal-stabilization transistor can receive the input complementary signal. The first and second signal-stabilization transistors can be low-voltage p-channel MOS (PMOS) transistors, and the first and second output signal transistors can be PMOS transistors.

The enable circuit has a first state that connects an external voltage supply to the sources of the first and second output signal transistors, and a second state that isolates the external voltage supply from the sources of the first and second output signal transistors in response to a signal that indicates the readiness of an internal voltage supply. The enable circuit can include first and second high voltage PMOS transistors having gates that receive the signal indicating that the internal voltage supply is ready.

The voltage level translator can further include a ready-signal generation circuit that delivers an external high voltage signal to the enable circuit to indicate that the internal voltage supply is ready for safe operation.

In a second aspect, the invention features a ready-signal generation circuit for providing a ready signal indicating that a voltage supply is at an operating voltage. The circuit includes a pair of input transistors. The gate of first input transistor receives the input signal, and the gate of the second input transistor receives an input complementary signal.

The ready-signal generation circuit also includes a pair of output transistors. The drain of the first output transistor is connected to the gate of the second output transistor, to the drain of the first input transistor, and to an output complementary signal node. The drain of the second output transistor is connected to the gate of the first output transistor, to the drain of the second input transistor, and to an output signal node. At least one of the pairs of input transistors and output transistors are unbalanced. An unbalanced pair



## DETAILED DESCRIPTION

This invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced or of  
5 being carried out in various ways. Also, the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having," "containing", "involving", and variations thereof herein, is meant to encompass the items listed thereafter and equivalents thereof as well as additional items.

10 The term "connected" is herein used to refer to components that are either in direct or indirect electrical communication. A direct connection is an uninterrupted interconnect pathway having an essentially non-variable resistance. An indirect connection includes additional components, such as transistors. Thus, an indirect connection can be variable. For example, the connection can have a variable resistance  
15 and/or can have a conductive state and an open state. For example, as generally used herein, two connected components may be connected via a transistor that provides a conductive path or an open circuit, depending on the state of the transistor.

The terms "core," "internal," and "low," depending on context, herein refer to components configured to operate with a voltage supply provides a relatively low  
20 voltage. These terms also may refer to such a supply, for example, a supply providing a voltage selected from a range of about 0.70 V to about 1.25 V ("VddL"). The terms "I/O," "external," and "high," depending on context, herein refer to components that are configured to operate with a voltage supply that provides a relatively high voltage. These terms also may refer to such a supply, for example, a supply providing a voltage  
25 selected from a range of about 2.25 V to about 3.75 V ("VddH"). A ground voltage ("Vss") is typically at zero volt.

For convenience, transistors that operate at a high voltage are in some instances herein referred to as "3V" transistors, and transistors that operate at a low voltage are in some instances herein referred to as "1V" transistors. This terminology is not, however,  
30 intended to limit the scope of the invention to the use of transistors operating at 1V and 3V.

**FIG. 1** is a schematic diagram of an example of a conventional voltage level translator **100** that converts an internal signal to an external signal. The translator **100** includes a differential transistor pair of four high-voltage transistors **111**, **112**, **161**, **162**. Two of the transistors **111**, **112** are NMOS-type; the gates of these transistors **111**, **112** receive an internal signal (**IN**) and an internal complementary signal (**INbar**). The remaining two transistors **161**, **162** are PMOS-type; the drains of these transistors **161**, **162** are connected to an output signal node **191** and an output complementary signal node **192**. As would be understood by one having ordinary skill in the microprocessor circuit arts, the translator **100**, in cooperation with other circuit components, can convert, for example, core logic signals of a low-voltage level to I/O signals of a high-voltage level.

Now referring to **FIG. 2**, various embodiments of the invention can provide voltage level translation with circuit-protection features and/or output-signal stabilization features. **FIG. 2** is a schematic diagram of an embodiment of a voltage level translator **200**, according to principles of the invention. The translator **200** includes a pair of input-signal transistors **211**, **212** and a pair of output-signal transistors **261**, **262**. The gates of the input-signal transistors **211**, **212** each receive one of a corresponding input signal and input complementary signal. The drains of the output-signal transistors **261**, **262** are each connected to a corresponding one of an output-signal node **291** and an output complementary signal node **292**.

The translator **200** also includes an enable circuit **270** and/or a signal stabilization circuit **230**. The enable circuit **270** may receive an internal supply-ready signal from an internal supply-ready signal generator **500**. The internal supply-ready signal generator **500** will be described in more detail with reference to **FIG. 5**. The translator **200** may also include a cascode circuit **220**, which can help to protect the input-signal transistors **211**, **212**, and will be described in more detail below.

The voltage level translator **200** can be included in, for example, a microprocessor to convert low-voltage signals output by the processor core into input signals for, for example, I/O circuitry. For example, each output-signal pad of a processor can have an associated translator **200** to shift the low-voltage signal produced by the processor to a high-voltage signal that can properly interact with high-voltage

external circuitry. In this example, if the processor has 128 output pads, the processor can include, for example, 128 translators **200**.

The translator **200** circuitry can be located in the periphery of the processor circuitry. Alternatively, the translator **200** circuitry can be located internally to the processor circuitry. Moreover, core logic and I/O circuitry can be located on a single  
5 integrated circuit chip, or can be on separate chips.

The input-signal transistors **211**, **212** are preferably 1V NMOS transistors. In this case, the translator **200** preferably includes a native-transistor circuit **250** to, in part, protect the input-signal transistors **211**, **212**. The embodiment of a native-transistor  
10 circuit **250** shown in **FIG. 2** includes two 3V NMOS transistors **251**, **252**. The gates of the transistors **251**, **252** can receive the input and input complementary signals, as shown, or may be connected to a low-voltage supply.

The transistors **251**, **252** have threshold voltages of about 0 volt, as controlled by the doping of channel regions during fabrication. For example, a threshold dopant  
15 implant step may be skipped for fabrication of the transistors **251**, **252**. The transistors **251**, **252** thus have threshold voltages that permit proper functioning in response to received input signals. That is, the transistors have threshold voltage levels less than that of an internal-voltage supply. The native transistors **251**, **252** can work in cooperation with the input signal transistors **211**, **212** to increase the switching speed of the translator  
20 **200**.

Due to their low threshold voltages, the native transistors **251**, **252** can reliably turn on in response to core voltage signals. Moreover, because the native transistors **251**, **252** are 3V devices, they can reliably handle external supply voltages. For example, the native transistors **251**, **252** can operate at voltages up to 10 V or greater.

The native transistors **251**, **252** also shield the low-voltage input-signal transistors **211**, **212** from high voltages. By permitting reliable use of low-voltage transistors in the translator **200**, low-voltage transistors can be used to provide better switching behavior. Since the translator **200** can utilize low-voltage transistors, which can be small in area relative to high voltage transistors, the low-voltage input signal transistors **211**, **212**, can  
30 help to conserve device area.

The output signal transistors **261**, **262** are preferably 3V PMOS transistors. The output signal transistors **261**, **262** can cooperate with the input signal transistors **211**, **212**

and the native transistors **251**, **252** to apply an output signal to the output-signal node **291** in correspondence with the input signal received by the input-signal transistor **211**.

The cascode circuit **220** can include two 1V NMOS transistors **221**, **222**. The gates of the transistors **221**, **222** each receive one of the input signal and the input complementary signal. The drains of the transistors **221**, **222** are each connected to a corresponding one of the native transistors **251**, **252**. The sources of the transistors **221**, **222** are each connected to a corresponding one of the input-signal transistors **211**, **212**. The transistors **221**, **222** can help to protect the input-signal transistors **211**, **212**. This can be helpful in part because the sub-threshold leakage currents of the native transistors **251**, **252** can be poorly characterized. The cascode circuit **220** can shield the drains of the input-signal transistors **211**, **212** from seeing all of the high-voltage swing.

**FIG. 3** is schematic diagram of an embodiment of an enable circuit **270a**, which can serve as the circuit **270** shown in **FIG. 2**. The enable circuit **270a** includes two 3V PMOS transistors **271**, **272**. Each of the transistors **271**, **272** is connected between the high-voltage supply and the source of one of the output-signal transistors **261**, **262**. The gates of the transistors **271**, **272** receive an internal supply-ready signal from, for example, the internal supply-ready signal generator **500**. When the ready signal is received, as, for example, a 3V signal, the transistors **271**, **272** are turned on and the translator permitted to function. The enable circuit **270a** thus can prevent erroneous functioning of the translator **200** and circuits supported by the translator **200**, when an internal power supply has not achieved normal operating conditions.

The enable circuit **270** helps to assure that the output-signal transistors **261**, **262** flip states in response to an input signal. If the internal supply fails to support a proper state transition of the output-signal transistors **261**, **262**, a direct current ("DC") path can appear leading to a DC discharge through the voltage level translator **200**. The internal supply can cause this problem when its voltage level is below the level required for proper transistor operation. The enable circuit **270** can thus disable the translator and avoid the occurrence of a DC path through the translator **200**.

A device, such as a processor, can include, for example, a second translator **200** to provide an output enable signal in addition to the first translator **200** that provides the output signal. An output enable signal can be delivered to external circuit components for their use in determining when, for example, interaction with the processor is possible.



**FIG. 4** is a schematic diagram of an embodiment of a signal-stabilization circuit **230a**, which can serve as the circuit **230** shown in **FIG. 2**. The stabilization circuit **230a** includes two 1V PMOS transistors **231**, **232**. Each of the transistors **231**, **232** has a drain connected to one of the drains of the input signal transistors **211**, **212**. The transistors **221**, **220** of the cascode circuit **220** can mediate the connections of the input signal transistors **211**, **212** to the stabilization circuit **230a**.

The stabilization circuit **230a** can provide, for example, a more consistent and accurate signal pulse width, and a balanced rise and fall time. That is, the output signal of the translator **200** can then better match the input signal. The circuit **230a** can also provide a speed improvement for the translator **200**. Further, the circuit **230a** can act as a voltage clamp to protect the input-signal transistors **211**, **212** from a high voltage.

Thus, the stabilization circuit **230a** can help to ensure that the pulse width of output logic signals remain close to that of incoming logic signals. Signal integrity can be desirable, for example, when an electronic system utilizes a precise internal time reference that should be preserved externally.

Now referring to **FIG. 5**, various embodiments of the voltage level translator **200** are well suited for use as the supply-ready signal generator **500**. Thus, each pad of a microprocessor can have, for example, a translator **200** to provide an output voltage signal, and a generator **500** to provide a ready signal to the translator **200**.

**FIG. 5** is schematic diagram of a more detailed embodiment of a supply-ready signal generator **500a**, which can advantageously serve as the generator **500** shown in **FIG. 2**. The supply-ready signal generator **500a** includes a pair of input-signal transistors **511**, **512**, which can be 1V NMOS-type, and a pair of output-signal transistors **561**, **562**, which can be 3V PMOS-type. The gates of the input-signal transistors **511**, **512** each receive one of a corresponding input signal and input complementary signal. The drains of the output-signal transistors **561**, **562** are each connected to a corresponding one of an output-signal node **591** and an output complementary signal node **592**. The generator **500a** also includes two low threshold voltage 3V NMOS transistors **551**, **552**. The gates of the transistors **551**, **552** receive input and input complementary signals from the internal-voltage supply. The generator **500a** also can include a resistive component **573**, including, for example, a chain of resistors, connected in parallel with one of the output-signal transistors **561**.

The parameters of the transistors **511**, **512**, **561**, **562** are preferably chosen to place the generator **500a** out of balance. For example, the width-to-length ratios (W/L) of gate dimensions can be chosen so that W/L for one output-signal transistor **561** is less than W/L for the other output-signal transistor **562**. Similarly, gate dimensions can be  
5 chosen so that W/L for one input-signal transistor **512** is less than W/L for the other output-signal transistor **511**.

Thus, the conductance of one input-signal transistor **511** is weaker than the other input-signal transistor **512**. Similarly, the conductance of one output-signal transistor **562** is weaker than the other output-signal transistor **561**. The resistive component **573**  
10 can pull up the output complementary signal node **592**, which must be pulled down by a weak input-signal transistor **511** and a low threshold voltage transistor **551**.

The pair of output transistors **561**, **562** can also be unbalanced by inclusion of the resistive component **573**. As will be understood by one having ordinary skill in the voltage-shifting circuit arts, resistive components and/or mismatched transistor  
15 parameters can be employed to provide an out-of-balance generator **500a**.

Functionally, the generator **500a** produces a ready signal at an external (high) voltage in response to reception of an inner voltage that exceeds a preset safe voltage level for an internal voltage supply. Thus, the supply-ready signal generator **500a** detects a ready condition of an internal voltage supply, and responsively produces an  
20 internal-supply ready signal. The ready signal can be delivered to, for example, the enable circuit **270**. In turn, the enable circuit **270** can permit operation of the voltage translator **200**.

Because the transistors of a device as-fabricated are typically well matched, the intentionally unbalanced transistors of the supply-ready signal generator **500a** can  
25 provide a good test of a safe internal operating voltage. The out-of-balance nature of the supply-ready signal generator **500a** can assure that a signal will not be generated by the unbalanced circuit of the supply-ready signal generator **500a** unless the supply voltage is also sufficient to properly operate other low-voltage transistors in the device. So, for example, by the time the supply-ready signal generator **500a** is capable of providing a  
30 high-voltage internal-supply ready signal, the translation circuit **200**, which is preferably balanced, will typically function correctly.

Now referring to **FIGS. 6, 7 and 8**, some alternative embodiments of signal-stabilization circuits are described. **FIG. 6** is schematic diagram of an embodiment of a signal-stabilization circuit **230b**, which can serve as the circuit **230** shown in **FIG. 2**. The stabilization circuit **230b** includes four 1V PMOS transistors **231b**. The transistors  
5 **231b** have their drains connected in series to one of the drains of the input-signal transistors **211, 212**. The transistors **221, 220** of the cascode circuit **220** can mediate the connections of the input-signal transistors **211, 212** to the stabilization circuit **230a**.

**FIG. 7** is schematic diagram of another embodiment of a signal-stabilization circuit **230c**, which can serve as the circuit **230** shown in **FIG. 2**. The stabilization  
10 circuit **230c** includes two 1V PMOS transistors **231c, 232c**. Each of the transistors **231c, 232c** has a drain connected to one of the drains of the input-signal transistors **211, 212**. **FIG. 8** is schematic diagram of still another embodiment of a signal-stabilization circuit **230d**, which can serve as the circuit **230** shown in **FIG. 2**. The stabilization circuit **230d** includes two 1V PMOS transistors **231, 232**. Each of the transistors **231d, 232d** has a  
15 drain connected to one of the drains of the input-signal transistors **211, 212**.

Having thus described several aspects of at least one embodiment of this invention, it is to be appreciated various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the  
20 spirit and scope of the invention. Accordingly, the foregoing description and drawings are by way of example only.

What is claimed is: